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New process chain for realisation of complex 2D/3D weft knitted fabrics for thermoplastic composite applications

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Abstract

Thermoplastic composites with a complex three-dimensional (3D) shape are attractive construction materials because of their good specific mechanical properties and their possibility to be processed very rapidly. The flat knitting technology bonded with the reinforcing hybrid yarns in horizontal and vertical direction is especially suited for the production of near-net-shape or fully-fashion multilayer weft knitted fabrics (MLG), which could be manufactured with proposed reinforced fibre alignment to obtain improved mechanical properties for high-performance applications. However, in the case of complex and strongly curved components, draping leads to undesired distortions of the stitch and reinforcement structures. In addition, shaping by draping often requires much time and manual effort. In order to effectively produce such knitted fabrics with near-net-shape, it is necessary to create a digital link between shape finding (3D geometry) and its realisation by knitting a 2D contour part and to develop a segmented take-down system for effective production of 3D multilayer weft knitted fabrics performs.

Selection and peer-review under responsibility of Conference organizers (MSE-Symposium B6).

Keywords: 3D-CAD; flat knitting; glass polypropylene hybrid yarn; multilayer weft knitted fabrics; 3D take-down system

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1. Introduction

For quite some time now textiles have offered the potential for innovative developments in diverse industrial sectors. Besides their classical application such as in garments and home textiles, the application of technical textiles has grown, in particular, in the field of fibre-plastic composites (FPC) for aeronautics and transport as well as machinery and plant engineering [1-6]. An extremely diverse spectrum of properties, which can be generated by using load-adapted reinforcement structures, will lead to prospective high growth rates, in particular for heavily loaded components [7-9]. To exploit this potential, interdisciplinary cooperation between textile technology and mechanical engineering is required. The following areas of focal research are emerging in this cooperation:

- Component design using load analysis
- Development of manufacturing processes required for near-net-shape preforming.

The following figure 1 shows the process chain which is described in this article step by step.

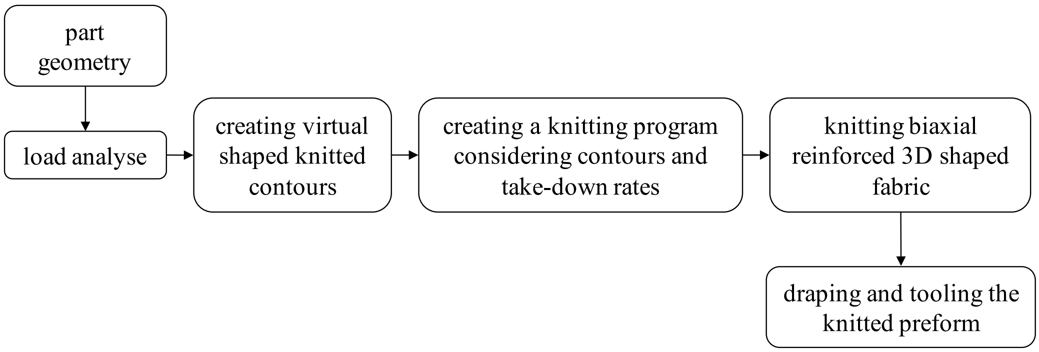


Fig. 1. Process chain for realisation of complex 2D/3D weft knitted fabrics

1.1 Material

FPCs consist of reinforcement fibres embedded in a matrix material. If high-performance fibres are used as reinforcement fibres, it is possible to achieve extreme material properties for specific material parameters, in particular strength, tensile modulus, temperature and flame resistance as well as resistance to chemicals. Among the most important and, at present, most frequently used high-performance fibre materials are glass, carbon and aramid fibres.

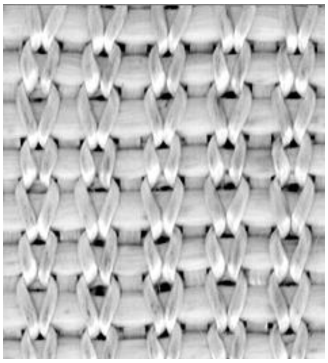
The matrix materials used are duroplastics and thermoplastics. Due to higher productivity, lower costs and better environmental compatibility as well as recyclability, thermoplastic matrix materials have recently been gaining increasing importance. What makes them attractive is not only the short process time in manufacturing but also the high tenacity of the composite material with its improved shock and impact properties.

However, the high viscosity of the thermoplastic matrix leads to problems during processing. Poor wetting behaviour of the reinforcement fibres prevents the formation of a homogeneous composite structure [10]. Previous investigations have shown that it is advantageous in the manufacture of thermoplastic FPCs to already combine the reinforcing component (high-performance filaments) and the matrix component (thermoplastic filaments or fibres) in the yarn structure. Five basic processes are known for the production of such hybrid yarns: twisting, wrapping, OE friction spinning, online hybrid spinning and the production of commingled hybrid yarns [11 - 17].

In online hybrid spinning, the glass and thermoplastic filaments are spun simultaneously at the same speed. In the same process, the two components are mixed and then sized and wound together as a finished hybrid yarn. Such parallel hybrid yarns are available on the market as TWINTEX® (company OCV Reinforcements and Composites), inter alia, as glass/polypropylene (GF/PP) combination in a very coarse graduation of hybrid yarn fineness.

Commingled hybrid yarns are produced by mixing high-performance filament yarns and thermoplastic filament yarns into one thread, using a modified texturising method with the subprocesses filament feed, filament opening, mixing and take-down [15]. Commingled hybrid yarns made of one reinforcement and one matrix component, e.g. glass/polypropylene, carbon/polyether ether ketone, carbon/polyphenylene sulphide and carbon/polyester are state of the art [12, 13, 17].

The investigations were conducted using the materials listed in figure 2.



Basic parameter	Parameters values
Stitch yarn fineness:	138 tex hybrid yarn (GF/PP)
Reinforcing yarn fineness:	TWINTEX® 1398 tex
Glass content by weight:	82%
Glass content by volume (composite):	62%
Warp/ Weft density:	2.76 yarns/cm
Areal weight:	928 g/m²
Base structure:	plain

Fig. 2. Reference material V1- multilayer weft knitted fabric

1.2 Biaxial flat knitting

FPCs are mainly produced in prepreg and preform processes. In preforming, a 3D reinforcing structure can be produced using the textile technologies of weaving, braiding, warp and weft knitting as well as tailored fibre placement (TFP) (an embroidery process) [10].

Multilayer flat knitting allows the introduction of additional yarn systems which combine the advantages of woven and knitted fabrics [18] and integrate up to eleven reinforcement yarn layers biaxially and up to five reinforcement layers multiaxially into the fabric in keeping with the stitches and the gauge (figure 3) [19-23].

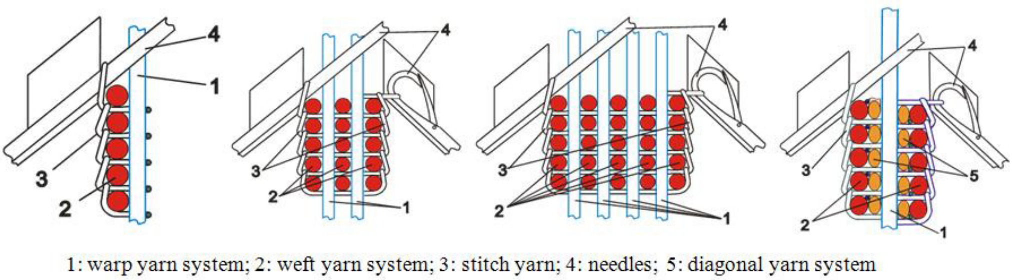


Fig. 3. Selected bi- and multiaxial multilayer weft knitted fabrics [10]

In the framework of this research project, a plain construction is used as basic construction for the biaxially reinforced structure. The stitch forming process hardly differs from conventional weft knitting. The weft yarns are laid in by a yarn guide as a filament in weft direction. The warp yarns are fed by yarn guide tubes in the direction of fabric take-down. The stitch yarns thereby link the weft yarns with the warp yarns. The limited space in the area of the working position of the biaxial flat knitting machine is illustrated in figure 3. The second needle bed is used for loop transfer and for needle bed racking to be able to produce form-fitted biaxial plain weft knitted fabrics in 2D and later on in 3D. Figure 4 schematically shows the construction of a two-layer biaxial weft knitted fabric on the fabric face and on the fabric back.

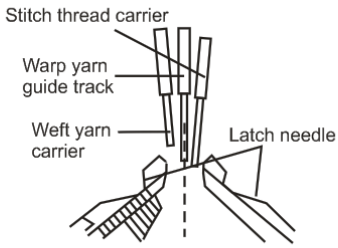


Fig. 3. Working position of a biaxial flat knitting machine [10]

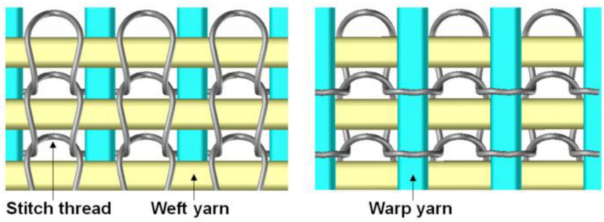


Fig. 4. Construction of a biaxial plain weft knitted fabric (left) fabric face; (right) fabric back

1.3 Construction, preforming

The use of the hybrid yarn material described above and the application of biaxial flat knitting are exemplified in a component (cabin carrier) of a function-integrated vehicle undercarriage system [23] to demonstrate the potential of filament-reinforced thermoplastics.

The cabin carrier has the task of joining the driver cabin to the vehicle undercarriage system (figure 5). The component geometry is based on a U-section characterised in particular by double-bent areas which cause difficulties in draping non-shaped flat prepregs. For that reason, near-net-shape textile preforms with a load-adapted yarn architecture are built in a biaxial flat knitting process.

With regard to processing, fibre-reinforced thermoplastics offer decisive advantages over fibre-reinforced duroplastics. To be mentioned are: unlimited storability of the prepregs even at room temperature, thermal formability and reformability for multiple times, simple processing technologies, shorter cycle times and recyclability of waste products [24].

Fig. 5. (left) Function-integrating vehicle system unit (FiF); (right) Demonstrator: cabin carrier [23]

2. Load analyses for determining the main reinforcement directions of the cabin carrier

For effective production of biaxially reinforced hybrid yarn knitted fabrics with appropriate loading and processing properties, it is necessary to insert shaping elements (dividing lines) for the production of the desired 3D geometry. Since the virtual dividing lines for shaping the biaxial weft knits can variably be placed and optimized in a computer-aided process, it is necessary to define the significant loading situations of the target application and to determine the necessary component design. Furthermore the material behavior of the composite material is required. Since the characteristic length of the structural part $L$and that of the internal composite architecture l meet the relation $L \gg l$, the structural part can be represented in a FE-simulation as homogeneous shell structure. However, this requires the knowledge about the respective effective material properties. Here a representative volume element (RVE) is elaborated to compute these properties for the structural-mechanical FE-simulation. Based on the biaxial knits (figure 1) and the micrographs of the composite structures (figure 6), the geometry parameters necessary for the textile reinforcement structure and the matrix were determined and used for modeling the RVE.

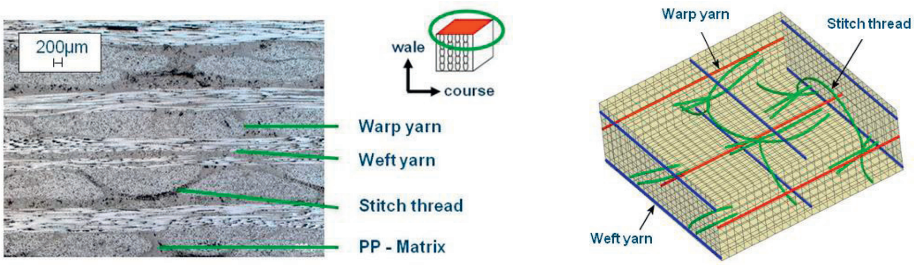


Fig. 6. (left) Polished cross-section of reinforced composite; (right) RVE-model

The homogenization method allows for the estimation of elastic and in-elastic material properties without the realization of expensive, often complicated and long-lasting experimental investigations [25, 26]. According to this approach, different cases of specific deformations including the application of periodic boundary condition to the RVE are simulated. A subsequent evaluation of the results gives the effective material properties which can be used in the macroscopic structural simulation.

One question in the conceptual design step of the cabin carrier concerns the material thickness. An essential criterion for this parameter is the deflection of the carrier at the front end. The critical load case is defined by a situation where a person steps onto the cabin. Since the fabric in the carrier has a locally changing orientation, the anisotropic material properties need to be assigned according to the expected principle directions.

The calculations showed that a thickness of approx. 6 mm is required for the cabin carrier. The following experimental investigations were performed in order to verify the results of the simulated load analysis of the cabin carrier (figure 7) [27].

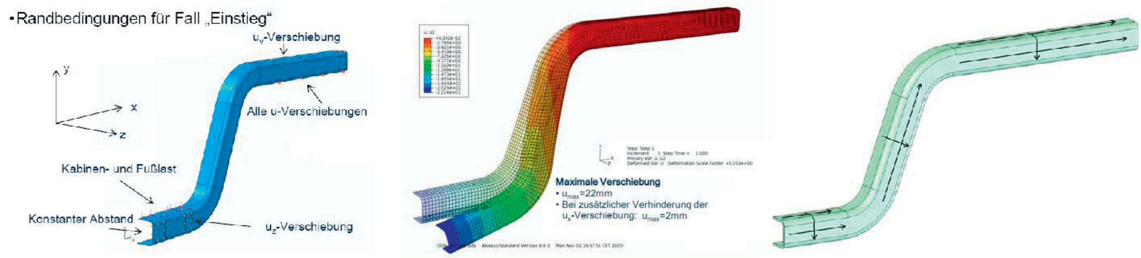


Fig. 7. Cabin carrier subjected to an assumed load (left, centre) and the determined reinforcement directions (right)

3. Procedure for manufacturing the cabin carrier

3.1 Creating shaped knitted contours using MATLAB

Projecting complex 3D shapes onto a 2D plane always entails structural distortion [28]. The aim is to achieve a developed 2D contour in which the area, lines and angles are largely preserved by arranging shaping elements on the virtual 3D surface. The resulting 2D part knitted according to this image should conform to the desired 3D component geometry and maintain the reinforcement direction. The procedure is shown in figure 8 for the outer reinforcing layer of the cabin carrier. Further layer construction is analogous. The change of geometric dimensions (width, height, radii) of the U-section with an increasing number of layers is taken into account.

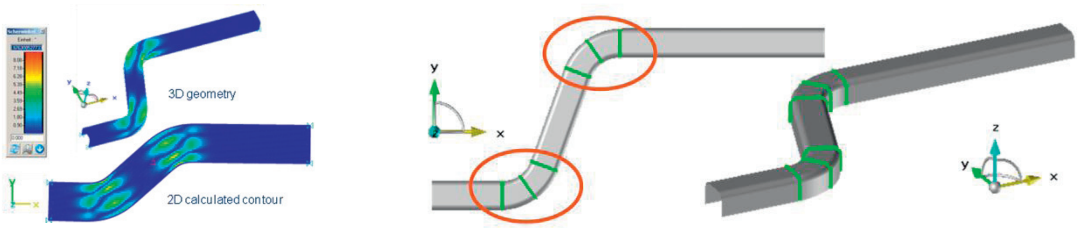


Fig. 8. (left) Distortion analysis of the calculated contour in 2D/3D; (right) Arrangement of dividing lines on the outer geometry of the cabin carrier

The dividing lines were determined based on the experience gained in the realization of the basic geometries and the sample geometries of completed projects [29-32]. The placement of dividing lines followed the geometry profile in the curved area (Figure 8). This step was followed by the investigation of the produced knitted part. To generate the 2D contour, the subareas were triangulated and the resulting meshes were geometrically projected onto a plane [33, 34].

The developed 2D pattern can be arranged to match the desired direction of reinforcement and can be processed using MATLAB that a closed contour for the component can be knitted (figure 9). During processing of the contour, it is important to ensure that in each case two rows of stitches (90 °) form a pair. This means that the last knitting needle becomes the first knitting needle after the reversal (figure 10).

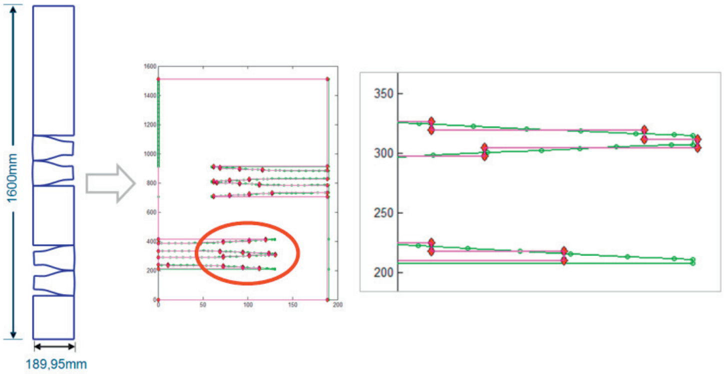


Fig. 9. Modification and generation of complete contours using *MATLAB*

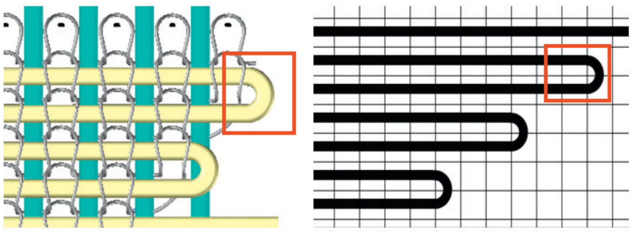


Fig. 10. Consideration the reverse of the weft reinforced yarn in the fabric

The calculation of the stepped curve to approach the knitting contour is done by taking into account the machine gauge and the required ratio between the weft and warp reinforced yarn (for example: weft density / warp density 1:1) and the reversal of the weft yarns (figure 11).

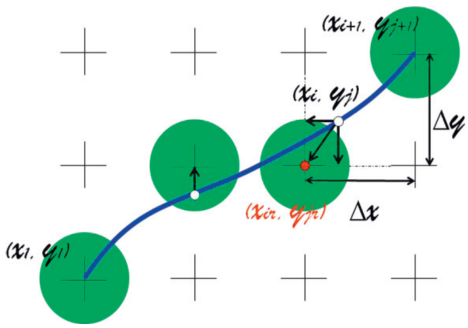


Fig. 11. Calculation of contour points for describing the stepped curve (considering the weft and warp density)

The generated contour from *Design Concept 3D* [35] will be imported as a DXF file in the developed program in *MATLAB* [36]. The data point of the curve (x_i, y_j) is recalculated as the data point of the stepped curve (x_{ir}, y_{jr}) with the help of rounding off rules in which the weft and warp density are taken into account (figure 11). During using a flat knitting machine with the machine gauge E7 and a selected ratio of weft and warp density of 1:1, the equations can be written as follows:

$$\Delta x = \text{distance between loops} = 25.4 / 7 = 3.63\ [mm] \quad (1)$$
$$\Delta y = \Delta x \cdot 2 \quad (2)$$
$$x_{ir} = \text{rounding}\ (x_i / \Delta x) \cdot \Delta x \quad (3)$$
$$y_{jr} = \text{rounding}\ (y_j / \Delta y) \cdot \Delta y \quad (4)$$

with

$i = 1 \ldots n,\ j = 1 \ldots n$

In Motive Module of the software *YX Knit Platinium Yxendis* [37] knitting symbols where attached to the stepped curve. In the software model of the company Steiger [38] all parameters required for the knitting process were set, including:

– the arrangement of construction elements,
– the yarn guide pairing,
– the definition of loop transfer processes,
– the stitch cam position (NP) and
– the take-down settings as well as the carriage speed [39].

The figure 12 shows that a digital connection between the 3D geometry, computer-supported determination of the 2D pattern cuts and the implementation of 2D pattern cuts (outline) into a knitting program for a weft knitting machine had created.

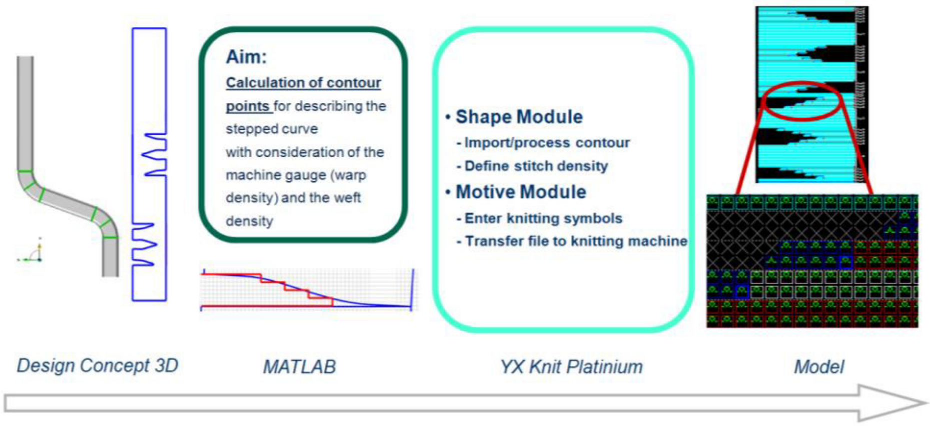


Fig. 12.Process chain 3D geometry - preform knitting program

3.2 Shaping by varying the number of stitches in the production of the cabin carrier

Shaping in flat knitting can be done by varying the number of stitches in the direction of courses and wales and by varying structure (variation of stitch length and construction) [19, 40]. The number of stitches formed can be changed with or without loop transfer.

3.2.1 Shaping variants without loop transfer

The realization without loop transfer is shown in figure 13 and is explained here in more detail.

a) Narrowing by pressing off loops is usually not recommended because this does not produce a firm edge to the knitted fabric.

b) The number of loops in the wale direction is changed using holding. This is achieved by parking a few needles over several courses while the adjacent needles continue to be active in the knitting process. The held loops remain on the parked needles until they are reintegrated into the knitting process. It should be noted that the maximum number of courses over which holding is possible limited, in particular, if brittle stitch thread material (GF/PP-HG) is used. The exact limits strongly depend on yarn material, stitch length and take-down values. Generally, holding is the preferred technique to join the edges of textile prepregs and is therefore an essential precondition for knitting a 3D geometry. The technique is easy to implement in manufacturing.

   Widening without loop transfer does not place any particular requirements on machine technology, even if the knitted fabric is biaxially reinforced. By adding further needles at the edge of the knitted fabric, the width can be enlarged as desired up to the maximum working width of the flat knitting machine.

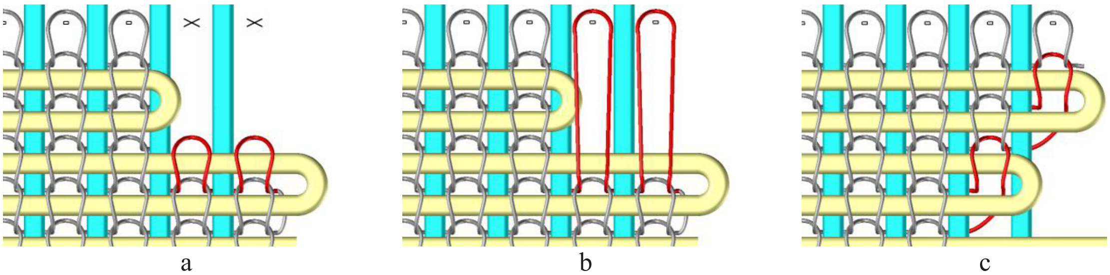
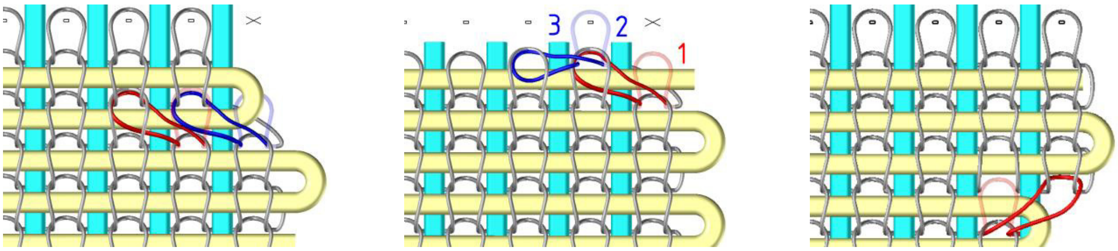


Fig. 13. Shaping variants without loop transfer (plain weft knitted fabric, fabric face)
Narrowing by pressing off loops (a), holding (b) and widening (c)

3.2.2 Shaping with loop transfer

Furthermore, the following variants exist for changing the number of stitches by loop transfer (figure 14). Loop transfer requires an individual needle selection feature of the biaxial flat knitting machine offers and a racking option for the two needle beds. The loops can be transferred as follows:

1. The loop to be transferred is first transferred to the needle of the opposite needle bed.
2. Subsequently, the needle bed is racked.
3. The previously transferred loop is then transferred to the adjacent needle of the initial needle bed.



a b c

Fig. 14. Shaping with loop transfer (plain weft knitted fabric, fabric face) Narrowing (a), binding off (b) and widening (c)

The two shaping variants without or with loop transfer are the standard in knitting without the integration of reinforcing yarns. As soon as warp and weft yarn systems are added for the production of multilayer knitted fabrics, shaping with loop transfer is prone to faults and should be avoided as far as possible.

During loop transfer, the transferring needle must be raised to its top position. As the reinforcing yarns are always located between two needles, there is a risk that these may be penetrated and destroyed by the raised needle (cf. figure 3). This is why holding and widening without loop transfer are the favored shaping techniques.

In variant V1 the edges can be easily joined since the outer points of the contours are positioned on a vertical line. To knit the developed pattern cut of variant V1, it is possible to apply the holding shaping technique.

3.3 Development and testing of a segmented take-down including the control system

The requirements for a 3D-MLG-take-down summarized in table 1 resulted from previous experiences regarding the 3D shaping of MLGs [41].

Tab. 1. Main requirements of a 3D take-down system

kinematics	• 50 take-off segments working independently from each other in 1m fabric width • mechanic decoupling of the take-down segments from each other • positive as well as negative infeed of take-down paths • infeed preciseness of $\pm$0,035 mm
geometry	• installation of the take-down in existing take-down-space of Steiger aries.3 • closest positioning of the take-down segments under the knitting area
control system	• position-controlled take-down • pre-turning and back-turning of the take-down independent from the knitting programm • take-down is programmable for different fabric widths

The development of the 3D MLG take-down is based on systematically designed solution principles for the take-down of textile structures. These are arranged and added in a solution matrix considering:

- force transmission between the take-down and the fabric,
- force transmission on the MLG layers,
- type of movement of the take-down elements and

– contact area between the take-down element and the MLG.

The preferred solution principle for a 3D-take-down system is shown in figure 15.

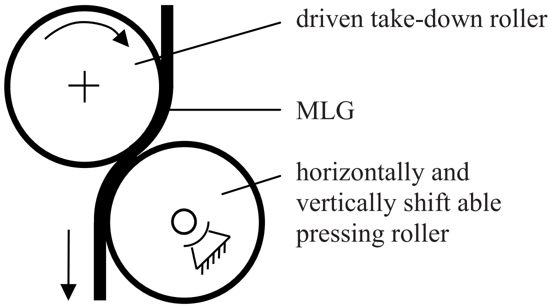


Fig. 15. Preferred solution principle for a 3D-take-down system

In order to realize 3D shaped knitted fabrics the take-down length and the number of involved takedown segments must match with the actual position and number of knitting needles. For the realization of different take-down length of neighbouring take-down segments the servomotors need to be coordinated in such a way that only low relative movements occur between the take-down segments during the infeed process. Consequently a distortion of yarns in the neighbouring fabric sections can be avoided. Entering of a negative take-down length results in a turning back of the accordant take-down segment and additionally, can be used to prevent a distortion of the yarns.

For the first step, the calculation of the take-down segments to be used is strongly connected to the carriage position. Therefore the carriage position is determined with the help of a shaft encoder attached to the main shaft of the carriage drive and is then standardized on a needle grid in accordance with the pitch of the knitting machine. The program stepping can therefore be started in any carriage position by the indication of the needle number. The graphic user interface for the 3D take-down system is presented in figure 16.

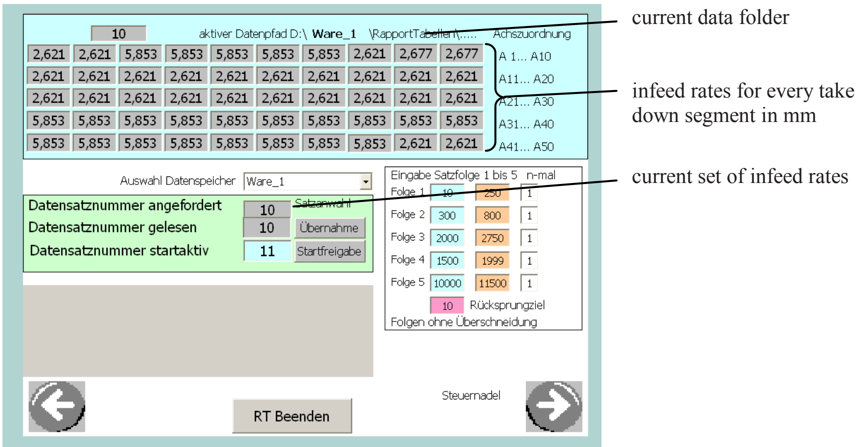


Fig. 16. Graphic user interface for programming the 3D take-down system

To verify the theoretical and systematic infeed error, the path-time diagrams of the drive shaft of one servomotor and the MLG, which is taken down by the appending take-down segment, are compared. Therefore the 3D take-down system was built up in an external testing device, which is shown schematically in figure 17.

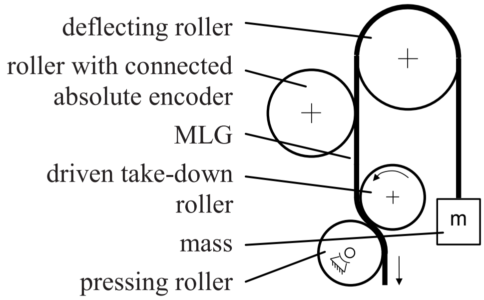


Fig. 17. Arrangement for testing the 3D take-down system

During the measurements pressing forces of 5 N, 25 N, 50 N and take-down forces of 2 N and 20 N where used. The needed infeed preciseness of ±0,035 mm per course will be reached independent from the take-down force by using a pressing force of 50 N. Because of this an adjustment of the infeed error by technical control isn't necessary. Furthermore the measurements show a decreasing infeed errror with rising number of infeeds. This take-down behaviour is traced back to the potential energy which is stored in the drive chain and will be reduced by every infeed according to the take-down force.

For knitting 3D fabrics, knitting techniques like loop transfer are necessary. For load removal of the loops during transfer a negative infeed of the take-down system is used. Therefore measurements (figure 18) with nineteen positive and seven following negative infeed rates are carried out. The amount of infeed refers to the machine gauge and is 3.62 mm per course.

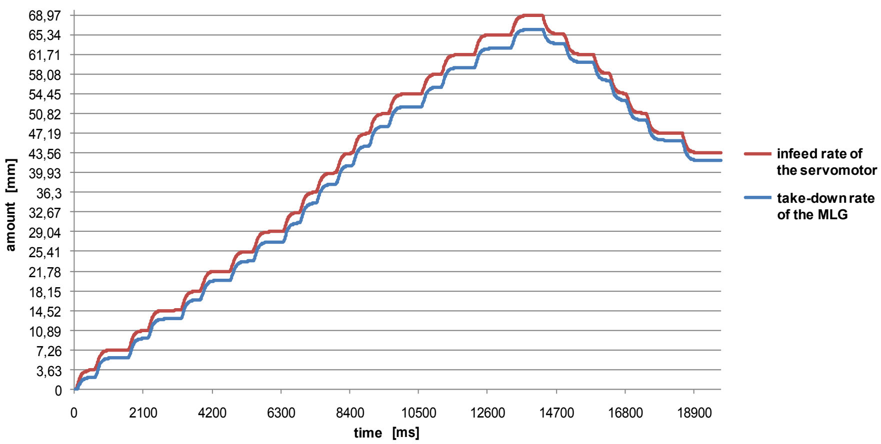


Fig. 18. Path-time diagrams of the drive shaft of one servomotor and the MLG

By using a pressing force of 50 N and a take-down force of 20 N the measurements show that the infeed error which has accumulated during the nineteen infeeds is used up to the half during the first six negative infeeds. From the seventh negative infeed, the infeed error increases again. In the result of the measurements the following reasons are indicated for a rising infeeed error:

– sliding of weft- and warp yarns during take-down process,
– varying frictional contact between the MLG and the pressing rollers respectively the take-down rollers because of the surface structure and

jamming the MLG flow in front of the take-down rollers caused by compacting the MLG.

After installing the 3D-take-down system in a *Steiger aries.3* knitting machine (figure 19), 2D-MLG out of GF/PP hybridyarns (fig. 1) with different weft yarn densities are knitted and evaluated to verify the take-down behaviour. Basic knowledge should be collected relating to machine settings (loop length), take-down rates and the consequence of which side the driven take-down roller have contact with the MLG.

Fig. 19. Top view of the implemented take-down system with opened needle bed

To reach a balanced ratio between weft and warp yarns, a weft yarn density of 2.76 yarns/cm is aimed. The knitting tests have shown, that the best take-down results, concerning to a minimum of slip and reproducibility, are achieved with a take-down configuration, where the pressing rollers have contact with the warp yarns and are positioned horizontally in a way, which the MLG clasps around the take-down rollers in an angle of 35 degree. The results of the knitting tests are shown in table 2.

Tab. 2. Weft yarn density relating to the loop length and the infeed rates of the 3D take-down system while the take down rollers have contact with the weft yarns and a wrap-around angle of 35 degree system

infeed rate for the take-down segments in mm	3.62			4.5
machine parameter for the loop length/loop length in steps / in mm	410/ 13.0	430/ 13.5	500/ 13.7	430/ 13.5
theoretical weft yarn density as a result of the chosen infeed rate in yarns per cm	2.76	2.76	2.76	2.22
measured weft yarn density in yarns per cm	3.09	3.18	4.33	2.82
weft yarn density ratio of theoretical and measured value	1:1.1	1:1.2	1:1.6	1:1.3

The test results show a MLG slip of 10 percent by using a small loop length of 13 mm. The aimed reproducible balanced ratio between the weft and warp yarns is reached by using an infeed rate of 4.5 mm per course and a loop length of 13.5 mm.

In summary the knitting tests indicate, that a reproducible production of MLG by use of the 3D take-down system will work with a limited loop length. On the one hand the loop length must be long enough to realise the aimed weft yarn density and on the other hand it must be short enough to transfer the take-down force from the weft yarns to the warp yarns. Short loop length reduces the drape ability of knitted MLG significant.

3D MLG performs for composite applications with reduced drape ability have no negative impact for following forming operations because for reaching the aimed geometry a remaining drape ability of only five percent is needed. On the other hand a low drape ability of 3D MLG preforms prevents displacement of reinforcing layers by handling during production process. Because of this a low drape ability of the 3D preform ensures a high-quality of the composite.

3.4 Knitting of the 2D pattern cut variant 1

For experimental investigations a modified flat knitting machine Steiger aries.3 in machine gauge E7 was used. As already mentioned, the modifications of the machine relate to the implementation of weft and warp yarn systems for the production of multilayer knitted fabrics.

3.4.1 Use of a conventional take-down system

The experiments were performed firstly with the standard segmented take-down system of the knitting machine (figure 20). This take-down system allows the setting of a segmental variable take-down effect only to a minor extent, in particular for the production of multilayer knitted fabrics. The selected take-down settings must therefore ensure that the necessary fabric tension for knitting is adjustable while maintaining faultless fabric production in those areas where shaping is done by holding. Figure 21 shows the resulting preform after experimental production.

Fig. 20. Modified flat knitting machine “Steiger Aries 3 $_{\text{ITB}}$“ and the conventional MLG take-down system

The 3D geometry of the preform cannot be fully produced by knitting due to an insufficient local take-down effect. The multilayer knitted fabrics have a high yarn density in the course direction of those areas where holding is used for shaping (structural inhomogeneity) (figure 21).

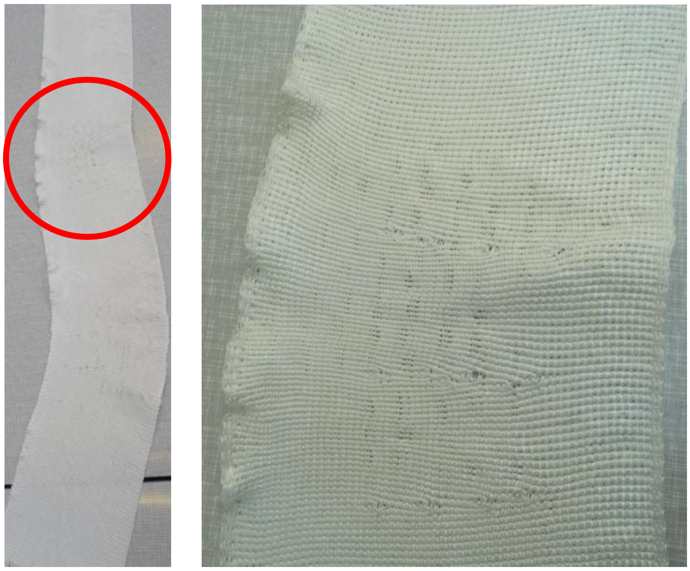


Fig. 21. Fabrication of knitting pieces without the 3D-take-down system (preform with structural inhomogeneity before draping)

Before the experiment with help of the developed 3D take-down, it’s necessary to define the take-down values for each take-down segment separately. Figure 16 shows the interface of the 3D take-down programming used. The infeed rates for each take-down segment as well as for each row would be the input in the program. In order to realize 3D shaped knitted fabrics, the take-down length and the number of involved take-down segments must match with the actual position and number of knitting needles.

Figure 22 shows the resulting preform after experimental production, which achieved a homogeneous areal density.

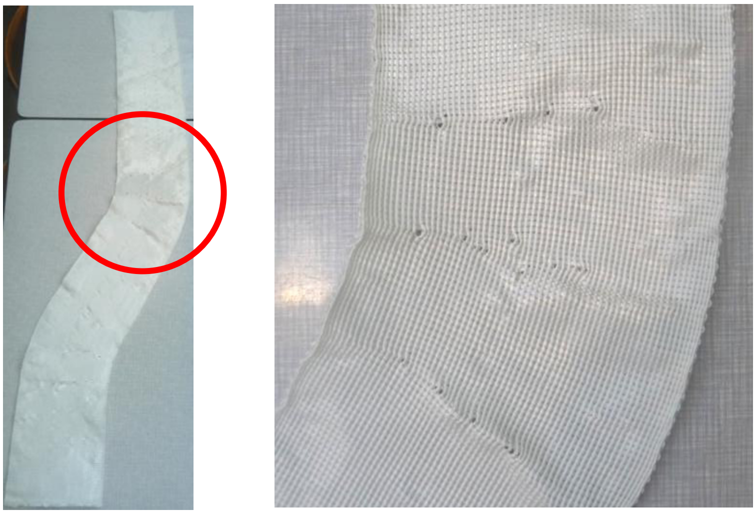
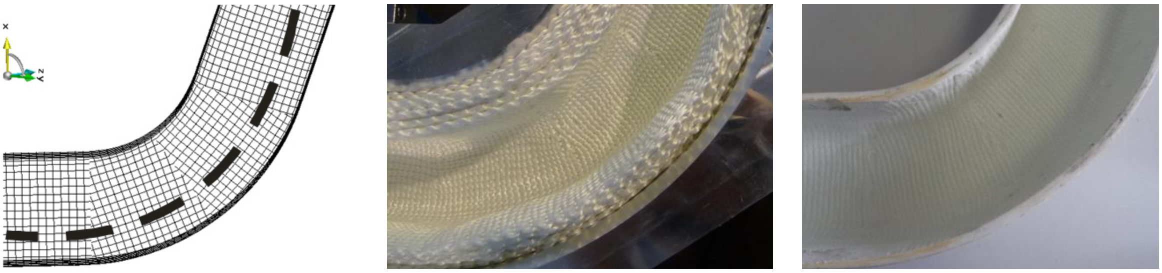


Fig. 22. Fabrication of knitting pieces with the 3D-take-down system

In the draping process subsequent to knitting, areas with increased yarn density in the course direction (figure 23) can be eliminated and the preform geometry can be adapted well to the draping tool (figure 23). The structure shows continuous warp reinforcement along the curvature of the cabin carrier and weft reinforcement at a right angle to the component edge to the greatest possible extent.



a b c

Fig. 23. Generation: simulation (a), before consolidation (b) and demoulded cabin carrier (c)

The preform is then consolidated in the autoclave (figure 24).

Fig. 24. Demoulded cabin carrier

Finally it should be noted that the following tasks need to be solved:

- avoid the cracking of loops in areas with a high degree of structural distortion depending on the used knitting material,
- find out the potential and the limitations of the 3D weft knitting process by using basic geometries, depending on number and arrangement of interlacing elements like loops and floating stitches),
- comparison between the aimed and realised direction of reinforcing fibres and
- homogenize and reduce warp yarn forces to decrease their influences on the 3D-take down effect.

4. Conclusion

The starting point of a new process chain to realise complex 2D/3D weft knitted fabrics is a load analyse for determining the main reinforcement directions and the needed thickness of the a structural element like a cabin carrier. Considering the 3D CAD geometry and the knitting technology and by the virtual alignment of reinforcing yarns on the 3D shape, preferred pattern cuts are chosen. These pattern cuts are transferred into machine control programs for the knitting machine using Design Concept 3D and MATLAB, that a closed contour for the component can be knitted. Hereby, all knitting parameters are determined such as yarn guide pairing, definition of loop transfer processes, stitch length, take-down adjustments or machine speed.

The first tests of these programs via knitting, show deficits (poor contour accuracy and structural inhomogeneity) in direct realization of 3D fabric preforms caused by a conventional take-down system with its insufficient local adjustability of the take-down effect. Because of this, a segmented 3D take-down system was developed and tested at the ITM, including the control system.

Tests of the 3D take-down system show a sufficient infeed preciseness according to pressing forces and take off forces for reproducible take-down behaviour during knitting. A reproducible production of MLG by the use of the 3D take-down system will work with a limited loop length of 13 mm and an infeed rate of 3.62 mm per course. The aimed reproducible balanced ratio between the weft and warp yarns is reached.

Experimental knitting of the cabin carrier preform with the 3D take-down system results in a better contour accuracy and a homogeneous areal density without structural inhomogeneity than knitting with conventional take-down systems.

As a result the preform geometry has continuous warp reinforcement along the curvature and can be adapted well to the draping tool.

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